

TITLE OF THE INVENTION

X-RAY CT SCANNER AND IMAGE PROCESSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is based upon and claims the
benefit of priority from the prior Japanese Patent
Application No. 2002-352446, filed December 4, 2002,
the entire contents of which are incorporated herein by
reference.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to an X-ray computed
tomography (CT) scanner and image processor for
reconstructing image data based on projection data
taken from a patient to be examined from multiple
15 directions.

2. Description of the Related Art

In recent years, display monitors have tended to
have higher resolutions, decreased size, and reduced
thickness. Also, their prices have declined. These
20 trends have promoted adoption of filmless technology in
the field of medical imaging diagnostics. The merits
of filmless capabilities are not limited to direct
consequences such as cost of film itself and the cost
spent for storage space. In the field of medical
25 imaging diagnostics, filmless technology offers the
advantages that the diagnostic accuracy is improved.

For example, an X-ray computed tomography (CT)

scanner stores projection data collected by multislice scans or helical scans. When diagnostic reading is done, the CT scanner reconstructs tomographic image data from the projection data according to reconstruction conditions specified by a human operator such as slice position, resolution, and image slice thickness and displays images. During diagnostic reading, the operator can observe any desired tomographic image while varying the slice position, resolution, and image slice thickness at will. In this respect, it is expected that the X-ray CT scanner provides much improved diagnostic accuracy compared with film-based reading in which the slice position, resolution, and image slice thickness are fixed since printed images are used.

However, this filmless technology has problems to be solved. An actual diagnostic reading session generally starts with reconstructing an image that covers a wide area with a very large image slice thickness and at a low resolution of about 512×512 pixels, for example. The image is then displayed. A judgment is made on this wide-area image as to whether there is any lesion. If any portion that is a suspicious lesion is discovered, the image slice thickness is reduced. Alternatively, the resolution is enhanced, and the display FOV is reduced, for example. An accurate image of 512×512 pixels is reconstructed.

This portion of image and surrounding portions are displayed over the whole monitor screen while maintaining the high resolution. Consequently, the legion can be identified more accurately. Furthermore, depending on the doctor, it is necessary to check the tissue structure of the lesion in detail. In this case, a more accurate image may be reconstructed by reducing the image slice thickness further and setting the resolution to a smaller display FOV, for example, and the image may be displayed.

In this way, lesional areas are narrowed down while increasing the resolution and reducing the image slice thickness gradually. Whenever the resolution and image slice thickness are varied, the reconstruction processing is repeated. The reconstruction processing is one of the most time-consuming processes. Therefore, the efficiency of the diagnostic reading work deteriorates. Especially, this technology is unsuited for screening examinations for many patients.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to provide an X-ray computed tomograph (X-ray CT scanner) and image processor providing improved efficiency of diagnostic reading work.

An X-ray CT scanner according to a first aspect of the invention has a gantry for collecting projection data about a patient, a reconstruction portion for

reconstructing multislice image data or volumetric
image data from the projection data at a given matrix
size, a storage portion for storing the reconstructed
image data, an input portion for entering a user's
5 instruction regarding magnification or demagnification
of image, and an image processing portion for
converting the matrix size of the stored image data
into a matrix size corresponding to the user's
instruction and varying the image slice thickness of
10 the stored image data into an image slice thickness
corresponding to the user's instruction.

An image processor according to a second aspect
of the invention has a storage portion for storing
multislice image data or volumetric image data about
15 a patient, an input portion for entering a user's
instruction regarding magnification or demagnification
of image, and an image processing portion for
converting the matrix size of the stored image data
into a matrix size corresponding to the user's
20 instruction and varying an image slice thickness of
the stored image data into an image slice thickness
corresponding to the user's instruction.

Additional objects and advantages of the invention
will be set forth in the description which follows, and
25 in part will be obvious from the description, or may be
learned by practice of the invention. The objects and
advantages of the invention may be realized and

obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

5 The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention, and together with the general description given above and the detailed description of the preferred embodiments given below, serve to explain
10 the principles of the invention.

FIG. 1 is a structural view of a CT scanner according to an embodiment of the present invention.

FIG. 2 is a graph in which the number of stacked slices and the degree of enhancement of high-frequency
15 components are plotted against the image display magnification factor controlled by the image processing control circuit shown in FIG. 1.

FIG. 3 is a flowchart illustrating a sequence of operations from scan to end of diagnostic reading
20 according to the present embodiment of the invention.

FIGS. 4A to 4C schematically illustrate the flow of processing for diagnostic reading illustrated in FIG. 3, together with examples of image.

DETAILED DESCRIPTION OF THE INVENTION

25 Embodiments of an X-ray CT scanner and image processor according to the present invention are hereinafter described with reference to the drawings.

X-ray CT scanners have various types including a rotation/rotation type in which an X-ray tube and a radiation detector rotate together around a patient and a stationary/rotation type in which a number of
5 detection elements are arrayed annularly and only an X-ray tube rotates around a patient. The invention can be applied to either type. In the following description, the X-ray CT scanner is assumed to be of the rotation/rotation type that prevails today.
10 Furthermore, to reconstruct tomographic image data about 1 slice, projection data derived by one full rotation around the patient, i.e., about 360° , is necessary. Furthermore, in the half scan method, projection data derived by a rotation of $180^\circ + \text{view}$
15 angle is needed. The invention can be applied to either reconstruction method. In the following description, an example in which tomographic image data is reconstructed from about 360° of projection data as in the former case is taken. One prevalent mechanism
20 of converting incident X-rays into charge is the indirect conversion type in which the X-rays are converted into light by a fluorescent material such as a scintillator and the light is then converted into electric charge by a photoelectric device such as
25 a photodiode. The other is the direct conversion type utilizing creation of electron-hole pairs within a semiconductor in response to X-rays and movement of

the pairs to the electrodes, i.e., photoconductive phenomenon. The X-ray detecting device may adopt either type. In this description, the former indirect conversion type is used. In recent years, X-ray CT
5 scanners of a so-called multiple-tube type in which pairs of X-ray tubes and X-ray detectors are installed on a rotating ring have been commercialized to a significant extent. Its peripheral techniques have been also developed to a considerable extent.
10 The present invention can be applied to both the prior single-tube X-ray CT scanner and multiple-tube X-ray CT scanner. In this description, the scanner is of the single-tube type.

A tomographic image is a representation of a cross
15 section of a tissue having some thickness. The thickness of the cross section of the tissue is referred to as the slice thickness. X-rays spread radially from the focus of the X-ray tube, pass through the patient, and arrive at the X-ray detectors.

20 Accordingly, the thickness of the X-rays increases with moving away from the focus of the X-ray tube. Customarily, the thickness of the X-ray at the center axis of rotation is defined to be the slice thickness. In this description, the thickness of X-rays at
25 the center axis of rotation is referred to as the slice thickness according to the customary usage. This convention is also applied to the width of the

detection device as viewed in the direction of slice. That is, where a detection device is expressed as having a sensitive width corresponding to some slice thickness, the sensitive width is greater than the slice thickness in practice. More specifically, it is necessary in practice to design the sensitive width to be greater than the slice thickness according to the ratio of the distance between the focus of X-rays and the detection device to the distance between the focus of X-rays and the center axis of rotation.

FIG. 1 is a block diagram showing the configuration of a computed tomography apparatus (CT scanner) according to the present embodiment. This scanner has a gantry 6 fitted with an annular rotating frame 2. This frame 2 is rotatably supported to a couch-gantry mechanism portion 3, which has a motor for producing a power to rotate the rotating frame 2. The motor is supplied with electric power from a mechanism control portion 4 and produces a power. An X-ray tube 13 and an X-ray detector 16 are installed on the rotating frame 2, the detector 16 having an array of detector elements. The X-ray detector 16 is placed opposite to the X-ray tube 13 via a patient 30 placed on the couch 1. A high voltage generator 12 applies a high voltage between the cathode of the X-ray tube 13 and the rotating anode, and supplies heating current to the cathode filament of the tube 13. Thermal electrons

emitted from the heated filament are accelerated by the high voltage and collide against the target of the rotating anode, thus producing X-rays. To permit continuous rotation, the X-ray tube 13 is connected
5 with the high voltage generator 12 via a slip ring 15. The mechanism control portion 4 and high voltage generator 12 supply electric power to the motor of the couch-gantry mechanism portion 3 to perform scans under control of a system control portion 5 for data
10 collection from multiple directions. The mechanism control portion 4 and high voltage generator 12 also apply a tube voltage and supply a filament-heating current to the X-ray tube 13.

A data acquisition system (DAS) 18 is connected
15 with the X-ray detector 16 via switches 17. The acquisition system 18 has plural channels of integrators for integrating the output current or voltage signal delivered from the X-ray detector 16, preamplifiers for amplifying the output signals from
20 the integrators, and analog-to-digital converters for converting the output signals from the preamplifiers into digital signals.

The data acquisition system 18 is connected with an image creating portion 7 via a noncontacting data
25 transfer circuit 19 utilizing light or magnetism. The output data from the data acquisition system 18 is generally referred to as raw data. Usually, the raw

data undergoes various kinds of preprocessing such as correction for achieving sensitivity uniformity between the channels. The preprocessed raw data is generally referred to as projection data. The image creating
5 portion 7 has a projection data storage circuit 20, which preprocesses raw data transmitted from the data acquisition system 18 via the data transfer circuit 19 and stores the preprocessed data as projection data. A reconstruction calculation circuit 21 reconstructs
10 tomographic image data based on the stored projection data. The tomographic image data is reconstructed as multislice data or volume data. Tomographic image data is reconstructed at the maximum resolution (maximum matrix size) determined by the number of channels in
15 the X-ray detector 16, the channel pitch, the sampling frequency for data collection, the reconstruction function of the reconstruction calculation circuit 21, and other factors. The tomographic image data is reconstructed with the smallest image slice thickness
20 or minimum voxel size determined by the helical pitch, data interpolation method, reconstruction method, and other factors. An image storage circuit 22 stores the tomographic image data reconstructed by the reconstruction calculation circuit 21.

25 An image processing portion 8 is connected with the image creating portion 7, and has an image processing control circuit 23, an image

magnification-demagnification circuit 24, a stack processing circuit 25, and a high-frequency enhancement circuit 26. An input portion 10 for entering a user's instruction regarding magnification or demagnification of image is connected with the image processing control circuit 23. An image magnification factor is entered as the user's instruction. An applicable method is selected as the input method from various methods. For example, the numerical value of the image magnification factor is entered. The image magnification factor is entered by selectively clicking on plural buttons corresponding to plural image magnification factors displayed on the viewing screen. Where a mouse with a wheel is adopted in the input portion 10, an image magnification factor corresponding to the rotational angle of the wheel is entered.

The image magnification-demagnification circuit 24 converts the matrix size of the tomographic image data stored in the image storage circuit 22 into a matrix size corresponding to the image magnification factor entered via the input portion 10 under control of the image processing control circuit 23. An image magnification factor is selected from a range from 0.5 to 1.0 (magnification of unity) and entered as shown in FIG. 2, for example. As an example, it is assumed that tomographic image data is reconstructed with a matrix size of 1024×1024 pixels and stored in

memory. When a magnification factor of 0.5 is entered, the tomographic image data is converted into a matrix size of 512×512 pixels. When a magnification factor of 1.0 is entered, the tomographic image data is
5 maintained at the matrix size of 1024×1024 pixels. The matrix size is converted by general image enlargement processing such as a method of thinning out pixels or a method of taking the average of the sum of plural pixels.

10 In the following description, it is assumed that the matrix size of 1024×1024 pixels is the maximum matrix size (highest resolution) overall determined by the number of channels in the X-ray detector 16, the channel pitch, the sampling frequency for data
15 collection, the reconstruction function of the reconstruction calculation circuit 21, and other factors.

The stack processing circuit 25 stacks sets of tomographic image data which have been converted in
20 matrix size by the image magnification-demagnification circuit 24 for plural frames under control of the image processing control circuit 23. The number of the sets of tomographic image data corresponds to the number of stacked slices, which in turn corresponds to the image magnification factor entered via the input portion 10.
25 As a result, the image slice thickness of the stored image data is converted into an image slice thickness

corresponding to the entered image magnification factor.

Where the image data has been reconstructed as volume data and stored in memory, the stack processing circuit 25 converts the initial image slice thickness (voxel thickness) into an image slice thickness corresponding to the entered image magnification factor by multiplanar reconstruction (MPR) rather than by stack processing. In the following description, it is assumed that the image slice thickness is modified by stack processing.

The number of stacked slices is determined by the image processing control circuit 23 according to the image magnification factor that is a user's instruction entered via the input portion 10. For example, as shown in FIG. 2, the number of slices is increased in a stepwise fashion with reducing the entered image magnification factor, and vice versa. Where an image magnification factor of 0.5 is entered, the number of slices is set to 5. Sets of tomographic image data about 5 consecutive slices around the slice position are stacked together (images are stacked together). In this case, if the reconstruction calculation circuit 21 reconstructs the tomographic image data with an image slice thickness of 2 mm, for example, the tomographic image data stacked together with the number of slices "5" correspond substantially to an image

slice thickness of 10 mm. When a magnification factor of "1.0" is entered, the number of slices is set to a minimum value of "1". No stacking is done. The image slice thickness of the tomographic image data is
5 maintained at 2 mm that was used during reconstruction.

The high-frequency enhancement circuit 26 is substantially constructed as a non-recursive digital filter or recursive digital filter. The high-frequency enhancement circuit 26 enhances high-frequency
10 components of the spatial frequencies about the tomographic image data created by the stack processing circuit 25 to an extent corresponding to the magnification factor entered via the input portion
15 10 under control of the image processing control circuit 23. The extent of enhancement performed by the high-frequency enhancement circuit 26 can be varied by switching coefficient sets applied to plural
multipliers in the high-frequency enhancement circuit (digital filter) 26 from the image processing control
20 circuit 23. The image processing control circuit 23 previously holds plural coefficient sets and supplies the coefficient sets selectively to the high-frequency enhancement circuit 26 according to the magnification
25 factor entered via the input portion 10. In practice, the coefficient sets are correlated to the magnification factor such that the high-frequency components are enhanced to a greater extent with reducing the entered

magnification factor and vice versa. For example, as shown in FIG. 2, when a magnification factor of "1.0" is entered, a coefficient set having such characteristics that the high-frequency components are hardly enhanced is selected. When a magnification factor of "0.5" is entered, a coefficient set showing the greatest extent of high-frequency enhancement among the plural coefficient sets is selected.

A display portion 9 is connected with the image processing portion 8. Tomographic image data created by the image processing portion 8 is displayed as a gray-scale image on a monitor 29 via a display storage circuit 27 and a display circuit 28.

FIG. 3 illustrates the flow (a sequence of operations) from scan performed by the X-ray CT scanner to end of diagnostic reading according to the present embodiment of the invention. Conditions (i.e., positioning, scan range, scan slice thickness, and helical pitch) are set in advance. After completion of the setting, helical or multislice scans are performed in practice to collect raw data from multiple directions within the scan range of the patient (step S1). The raw data is sent to the projection data storage circuit 20 from the X-ray detector 16 through the switches 17, data acquisition system 18, and data transfer circuit 19, and stored there (step S2). Based on the stored projection data, tomographic image data

about plural slices centered at the specified slice position are reconstructed with the minimum image slice thickness (assumed to be 2 mm, in this embodiment) and maximum matrix size (assumed to consist of 1024 x 1024 pixels, in this embodiment) in the reconstruction calculation circuit 21. The data are stored in the image storage circuit 22 (step S3).

Then, a message for making an inquiry as to whether the whole image is displayed at high resolution or not is displayed on the monitor 29 together with "YES" and "NO" command buttons under control of the system control portion 5 (step S4). When the "YES" command button is clicked in step S4, a reconstruction is performed by the reconstruction calculation circuit 21 in step S3. All image data stored in the image storage circuit 22 are sent to the display storage circuit 27 under the conditions where the magnification factor is 1.0, i.e., the high resolution of 1024 x 1024 pixels is maintained. That is, neither magnification nor demagnification is performed by the image magnification-demagnification circuit 24. Also, slice images are not stacked. That is, the individual images are maintained with the number of slices set to 1 by the stack processing circuit 25. Furthermore, high-frequency components are not enhanced by the high-frequency enhancement circuit 26. The images are then displayed on the monitor 29 at high resolution via the

display circuit 28 (step S9).

When the "NO" command button is clicked in step S4, the image data stored in the image storage circuit 22 are converted into a matrix size of 512×512 pixels by the image magnification-demagnification circuit 24 under the conditions where the magnification factor assumes a minimum value of 0.5. Data about five images around the slice position with the maximum number of slices of "5" are added by the stack processing circuit 25 (FIG. 4A). Furthermore, the data undergo the maximum extent, high-frequency enhancement by the high-frequency enhancement circuit 26 (FIG. 4B). The images are displayed at low resolution on the monitor 29 (step S5). Under conditions where the magnification factor assumes the minimum value of "0.5", an image of a wide range in the patient is displayed on the viewing screen (e.g., 512×512 pixels) of the monitor 29. This image has a large slice thickness of 10 mm, for example. In addition, the high-frequency components have been enhanced to a maximum extent. Therefore, it is easy to check whether there is any lesion. It is also easy to confirm the location.

Then, a message for making an inquiry as to whether there is a lesion is displayed on the monitor 29 together with the "YES" and "NO" command buttons under control of the system control portion 5 (step S6). When the "NO" command button is clicked, this

diagnostic reading inspection ends. On the other hand, when the "YES" command button is clicked, a message for making an inquiry as to whether the whole image is displayed at high resolution is displayed on the monitor 29 along with the "YES" and "NO" command buttons (step S7). When the "YES" command button is clicked, the program goes to the step S9, and all images are displayed at high resolution on the monitor 29.

10 When the "NO" command button is clicked in step S7, the program proceeds to step S8. In the step S8, the diagnostic reader (human operator) moves the mouse 10 right, left, and back and forth on the mouse table to bring the pointer onto the lesion. The reader also
15 rotates the wheel of the mouse 10 while holding the pointer at that position. A magnification factor corresponding to the number of rotations or rotational angle is entered. For example, whenever the wheel of the mouse 10 is rotated through 5°, the magnification
20 factor increases in an increment of 0.05 within the range from the initial value of 0.5 to the maximum value of 1.0.

 For example, when a magnification factor of 0.75 is entered, the matrix size of the tomographic image
25 data stored in the image storage circuit 22 is converted into a matrix size of 768 × 768 pixels. Three slices around the slice position are stacked.

The data undergo moderate high-frequency enhancement.
The images are displayed about the position of the
pointer on the monitor 29. Under the conditions where
the magnification factor is a moderate value of 0.75,
5 the lesion of the patient is displayed somewhat
enlarged on the viewing screen of the monitor 29.
This image has a general image slice thickness of 6 mm,
for example. The high-frequency components are
slightly enhanced. Accordingly, it is possible to
10 identify the position of the lesion in further detail.

When a maximum magnification factor of 1.0 is
entered by manipulating the wheel of the mouse 10, the
tomographic image data stored in the image storage
circuit 22 are displayed at high resolution around the
15 position of the pointer on the monitor 29 while kept
in high-resolution state (1024 x 1024 pixels) without
undergoing either stacking processing or high-frequency
enhancement (see FIG. 4C). Under conditions where the
magnification factor assumes a maximum value of 1.0,
20 the lesion of the patient is displayed enlarged on the
viewing screen of the monitor 29. Furthermore, with
respect to this image, the image slice thickness has
a small value of 2 mm, for example. In addition, the
high-frequency components are not enhanced or only
25 slightly enhanced. Consequently, the tissue structure
of the lesion can be checked in more detail.

As described so far, tomographic image data is

reconstructed with a maximum matrix size and stored
in memory. When the display magnification factor is
modified, the matrix size is modified to cope with the
tomographic image data previously reconstructed with
5 the maximum matrix size. The image slice thickness is
also modified similarly. The processing for modifying
the matrix size and image slice thickness is much
fewer in number of steps than the processing for
reconstructing tomographic image data and hence the
10 processing time can be shortened greatly. Accordingly,
the wait time of the diagnostic reader can be shortened
compared with the case where reconstruction of
tomographic image data is repeated whenever the display
magnification factor is modified as in the prior art.
15 In consequence, the efficiency of the diagnostic
reading work can be improved.

Furthermore, the image can be optimized for the
purpose of the diagnostic reading that varies according
to the magnification factor (such as identification of
20 the position of a lesion or detailed diagnosis of the
tissue structure) by automatically varying the extent
of enhancement of the high-frequency components
according to the magnification factor and automatically
varying the number of stacked slices, i.e., the slice
25 thickness. For this reason, the operation for setting
the extent of enhancement of the high-frequency
components is dispensed with, as well as the operation

for setting the number of slices (slice thickness).
The burden on the diagnostic reader during work can be
alleviated.

Additional advantages and modifications will
5 readily occur to those skilled in the art. Therefore,
the invention in its broader aspects is not limited to
the specific details and representative embodiments
shown and described herein. Accordingly, various
modifications may be made without departing from the
10 spirit or scope of the general inventive concept as
defined by the appended claims and their equivalents.